Highly Reflective and Highly Textured Al/Ag/ZnO Back Reflector for a-Si Based Solar Cells

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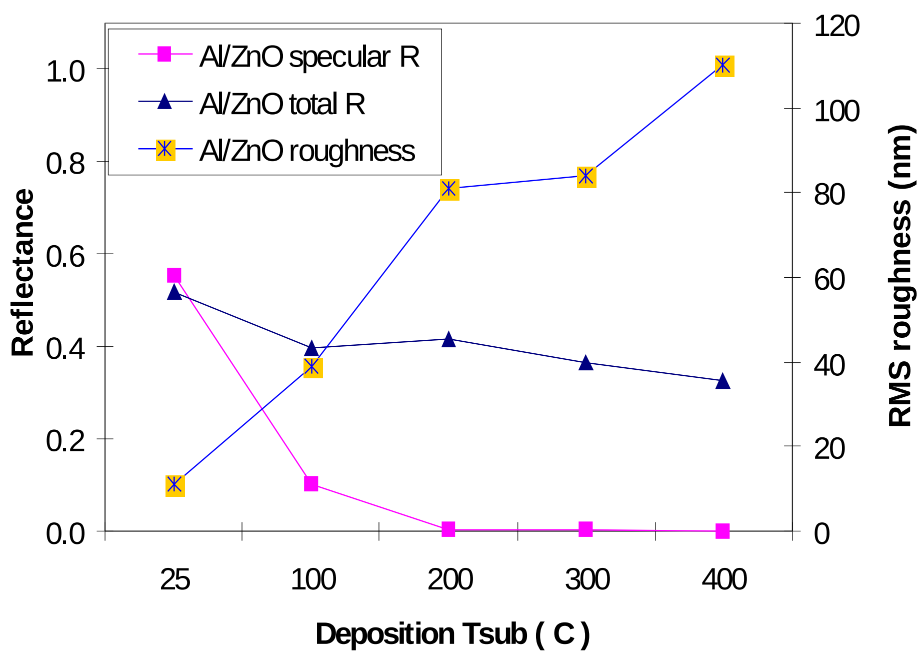
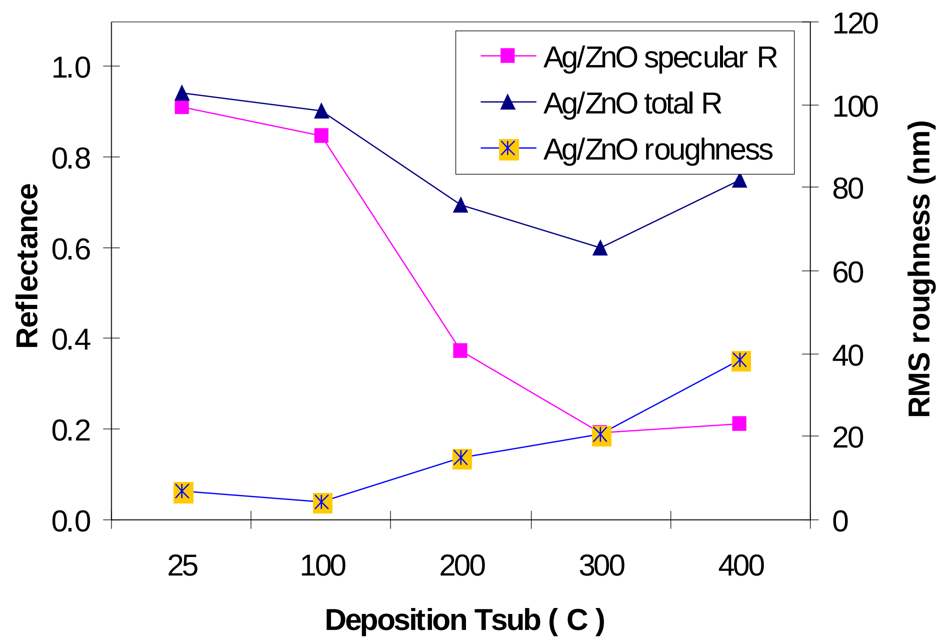
Introduction

- High efficiency solar cells require high performance back reflector that is both highly textured and highly reflective
- Metal (Al or Ag) deposited at high temperature and low rate is usually highly textured but not as reflective
- Metal (Al or Ag) deposited at low temperature and high rate is usually highly reflective but not textured
- Ag has higher reflectance than Al at wavelength (600-1000nm)
- Used Al (deposited at relatively low Ts) and Ag (deposited at low Ts) to form stacked structure to enhance both texture and reflectance

Comparison of Al/ZnO and Ag/ZnO Back Reflectors

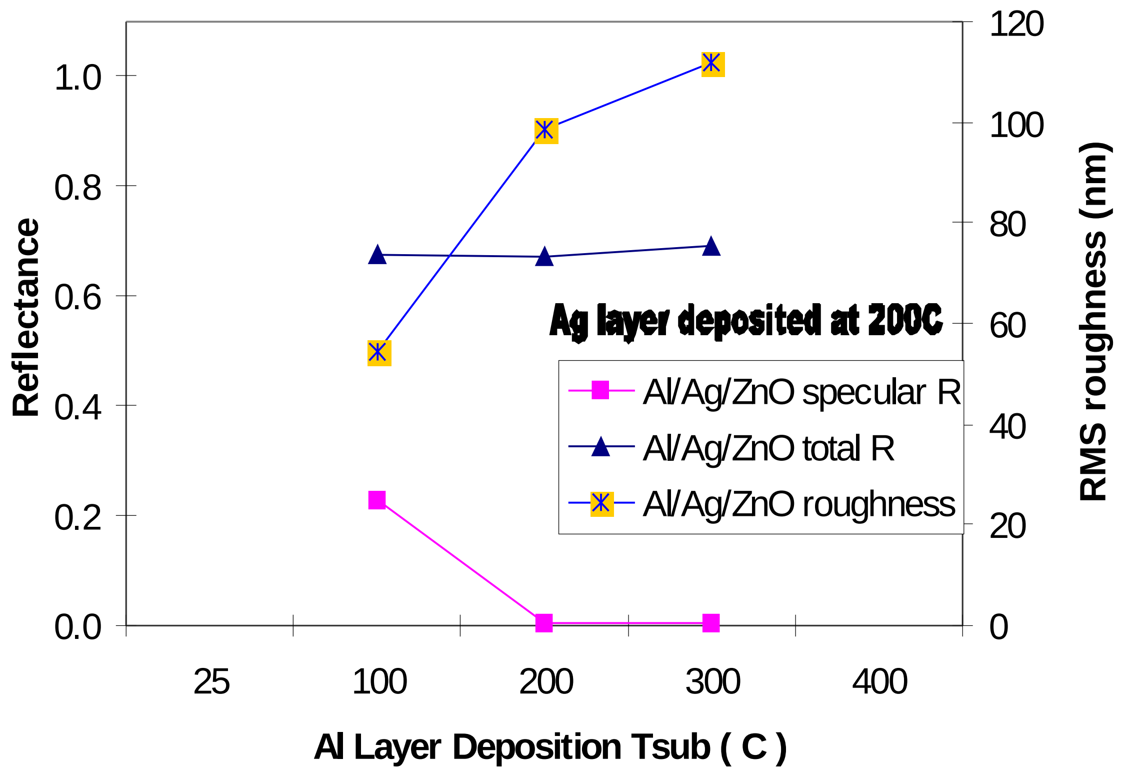




Al provides sufficient texture even at low Ts, but the reflectance is low.

Ag provides high reflectance, but the texture is low even at high Ts (400 C)

Al/Ag/ZnO Back Reflector compared with Al/ZnO and Ag/ZnO



- **Al/Ag/ZnO has similar total reflectance as Ag/ZnO**
- **Al/Ag/ZnO has similar RMS roughness as Al/ZnO**

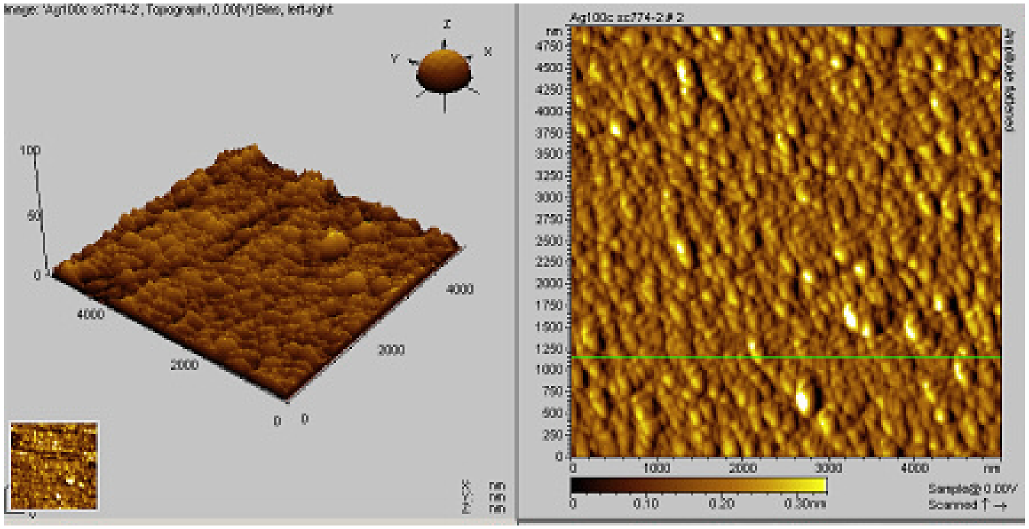
<u>Al/Ag/ZnO can be made highly textured & highly reflective</u>

An air exposure (oxide layer) is desirable at the Al/Ag Interface to prevent alloying

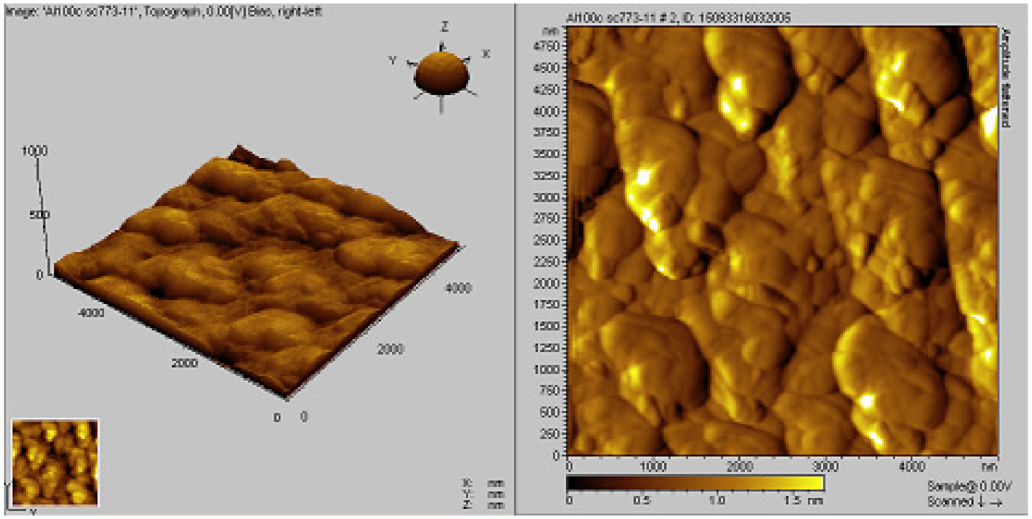
structure	Specular R	Total R	RMS (nm)
Al(200C)/vacuum/Ag(200C)/ZnO	0.026	0.229	51.6
Al(200C)/air/Ag(200C)/ZnO	0.004	0.673	98.7
Ag(200C)/ZnO	0.374	0.696	15.1
Al(200C)/ZnO	0.003	0.415	80.9

- Without air exposure between Al and Ag deposition, Al and Ag will alloy together and the alloyed layers in Al_xAg_{1-x}/ZnO structure show total reflectance even lower than that of Al/ZnO structure.
- In our Al/Ag/ZnO structure, a thin layer of alumina may be formed in air between Al and Ag films to prevent the alloying, thus preserve the texture of Al and reflectance of Ag.

AFM Pictures of Ag and Al Layers

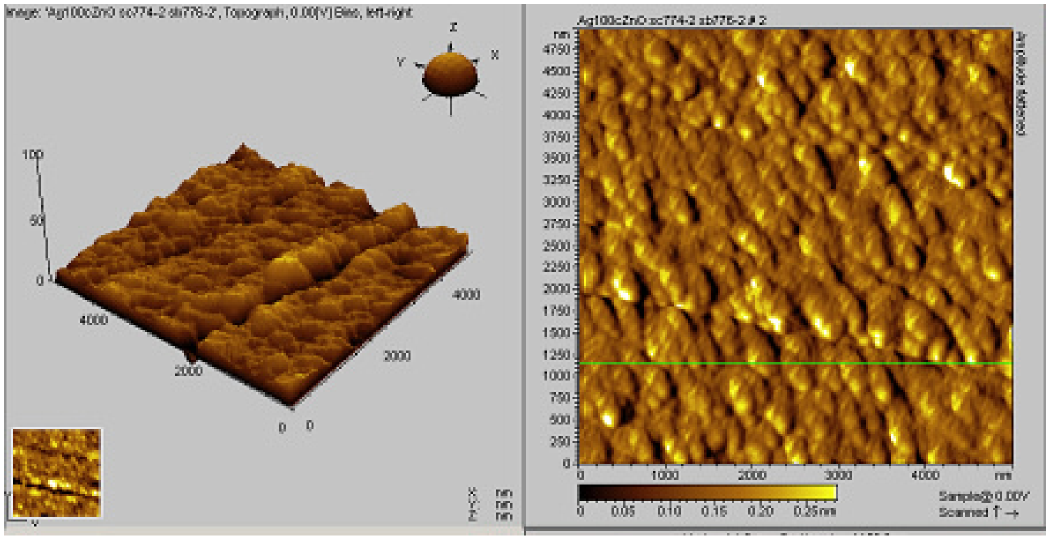


Ag (100 °C)
RMS=3.4nm

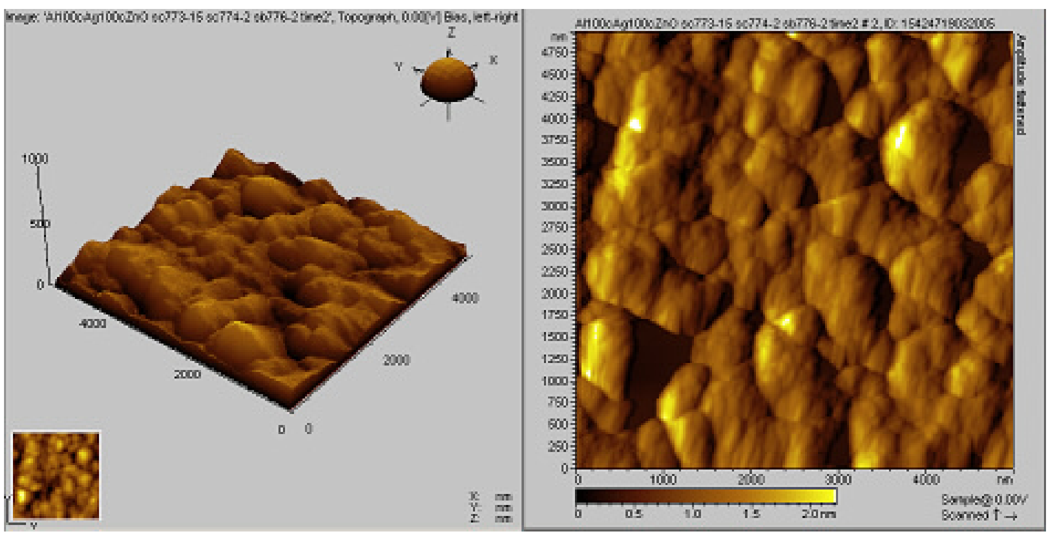


Al (100 °C)
RMS=34.7nm

AFM Pictures of Ag/ZnO and Al/ZnO Back Reflector Layers



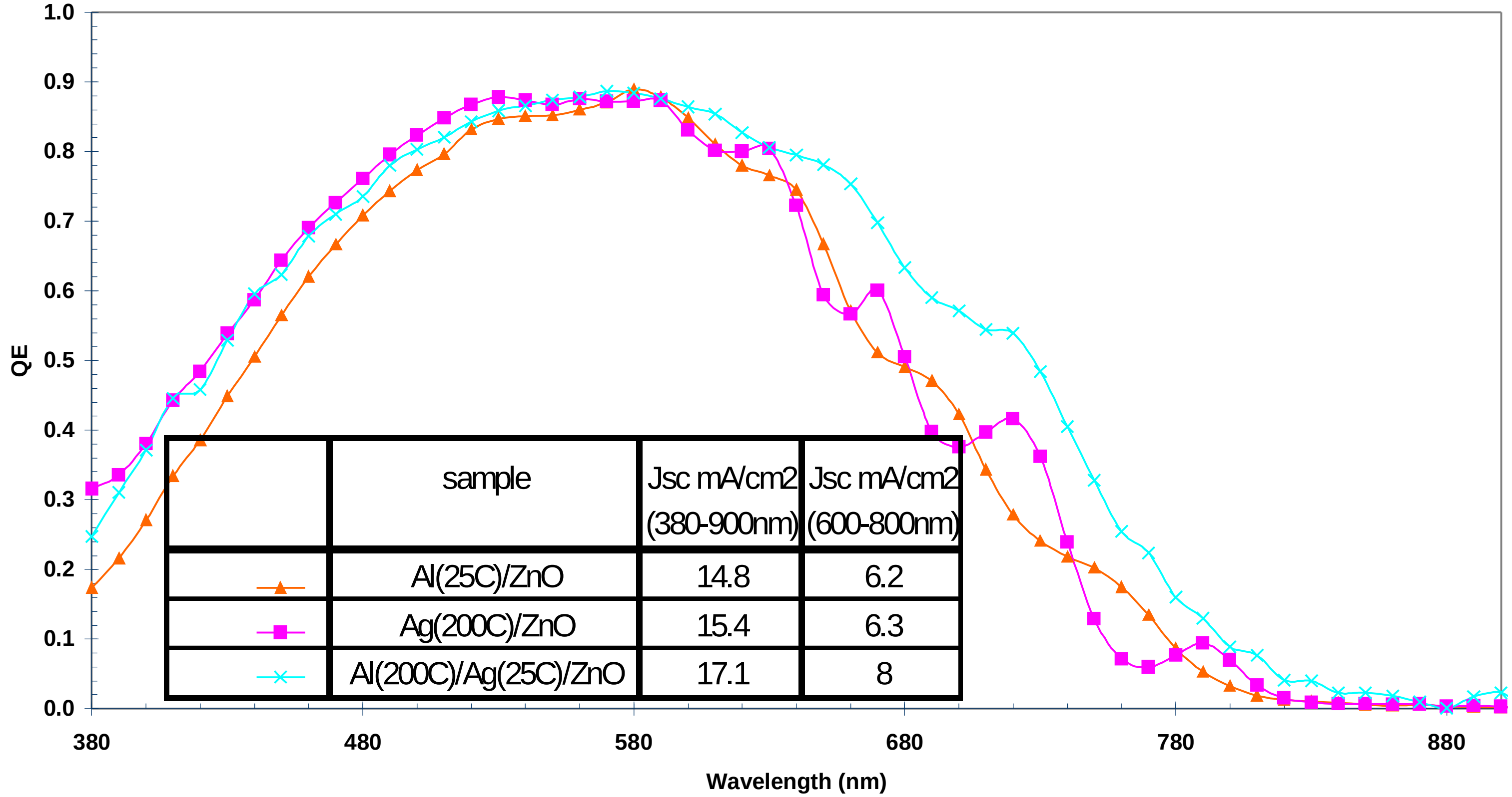
Ag (100 °C) / ZnO
RMS=4.4nm



Al (100 °C) / Ag (100 °C) / ZnO
RMS=53.1nm

QE Results of Al/Ag/ZnO Back Reflector Compared with Ag/ZnO and Al/ZnO

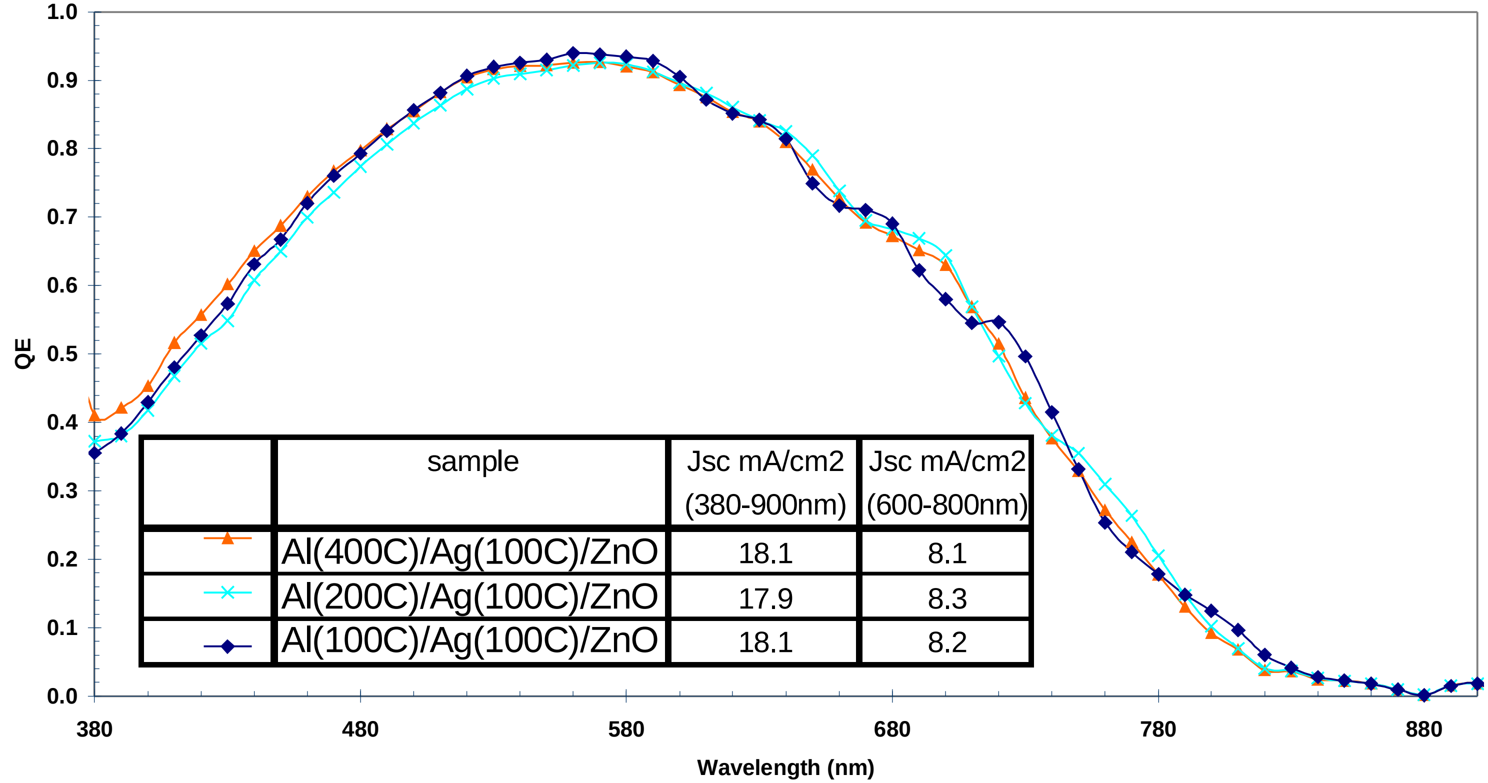
UT-BR research: a-SiGe:H i-layer mid-cell
(90' deposition time)



	sample	Jsc mA/cm2 (380-900nm)	Jsc mA/cm2 (600-800nm)
▲	Al(25C)/ZnO	14.8	6.2
■	Ag(200C)/ZnO	15.4	6.3
×	Al(200C)/Ag(25C)/ZnO	17.1	8

QE Results of Al/Ag/ZnO Back Reflectors with Al Deposited at Different Ts

UT-BR research: a-SiGe:H i-layer mid-cell
(90' deposition time)



	sample	Jsc mA/cm2 (380-900nm)	Jsc mA/cm2 (600-800nm)
▲	Al(400C)/Ag(100C)/ZnO	18.1	8.1
×	Al(200C)/Ag(100C)/ZnO	17.9	8.3
◆	Al(100C)/Ag(100C)/ZnO	18.1	8.2

Conclusion

- Highly textured and highly reflective back reflector is obtained using a Al/Ag/ZnO structure
- Al/Ag/ZnO back reflector has similar reflectance as Ag/ZnO and similar texture as Al/ZnO.
- Air exposure is important before Al and Ag layers to preventing alloying which reduces both the reflectance and texture of the stacked layers
- Solar cell results show that Al/Ag/ZnO structure has better performance at long wavelength range than Ag/ZnO structure.

Light-Assisted Shunt Passivation

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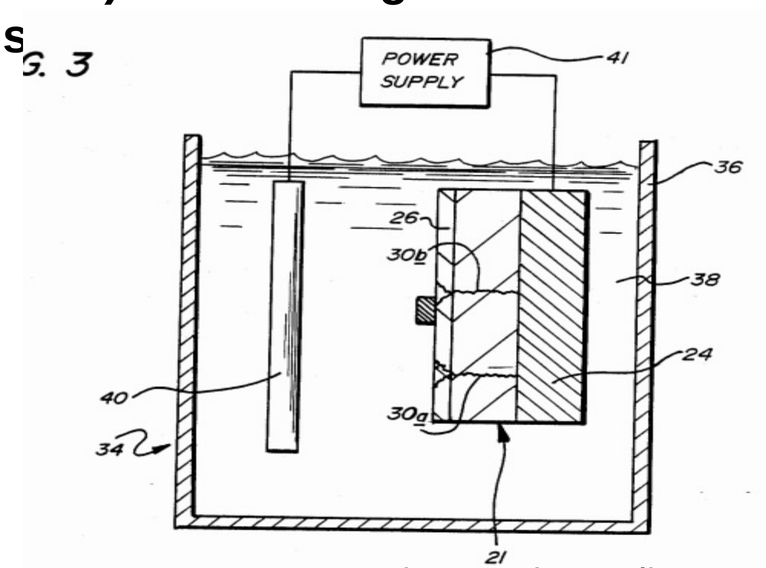
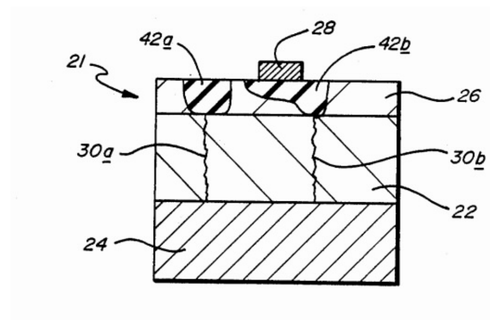
Introduction

Nath et al/ECD Process for shunt passivation

- **The device being treated is immersed in electrolyte and an electrical bias is applied to it.**
- **Converts transparent conducting oxide (TCO) in contact with (and near) shunted regions of device to an insulator, thereby isolating the s**





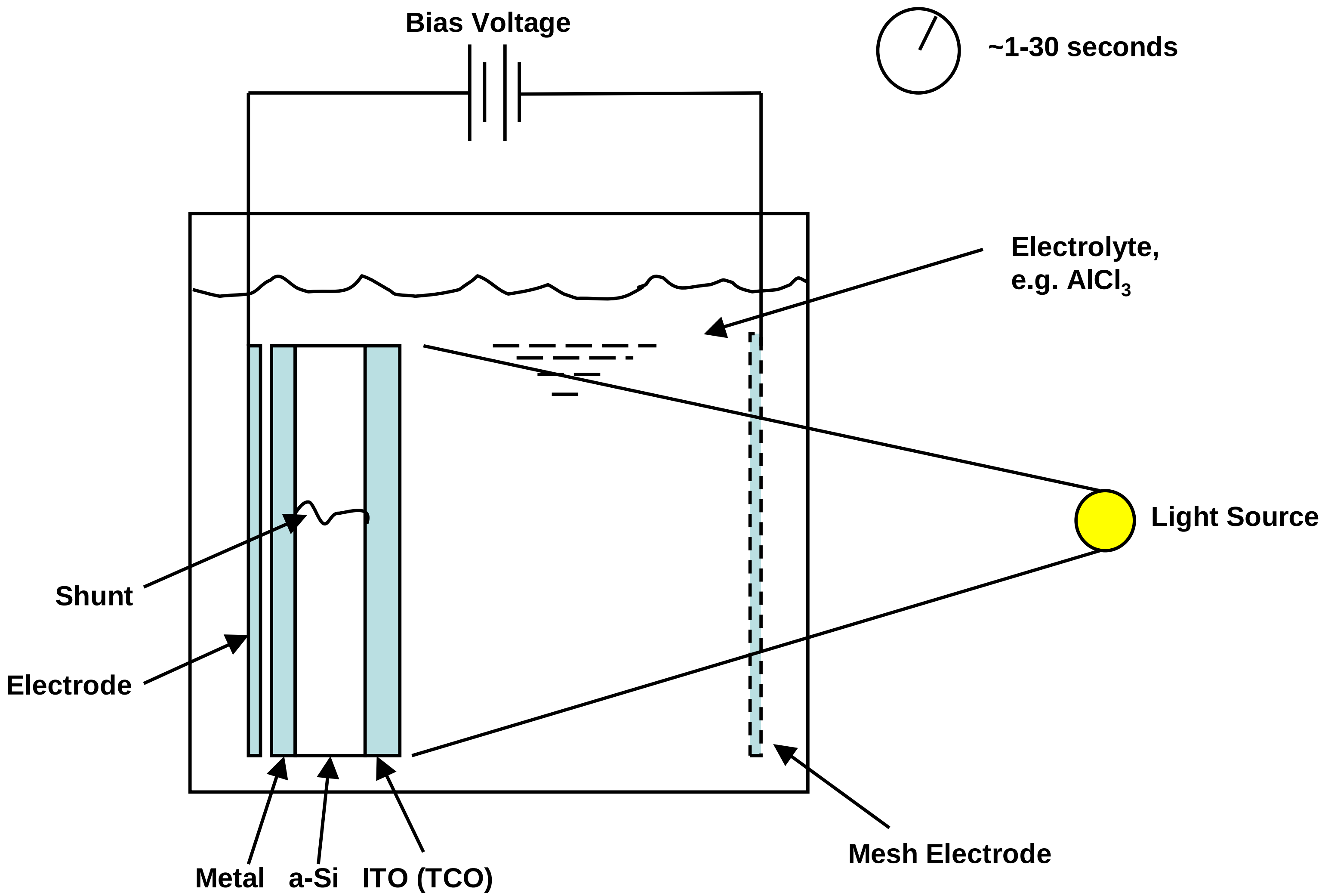
US Patent 4,729,970: Nath P. and Vogeli, C, *Conversion process for passivating short circuit current paths in semiconductor devices*, assigned to ECD

Nath, P, et al., *Conversion Process for Passivating Current Shunting Paths in Amorphous Silicon Alloy Solar Cells,* Appl. Phys. Lett. 53(11), Sep 1988.

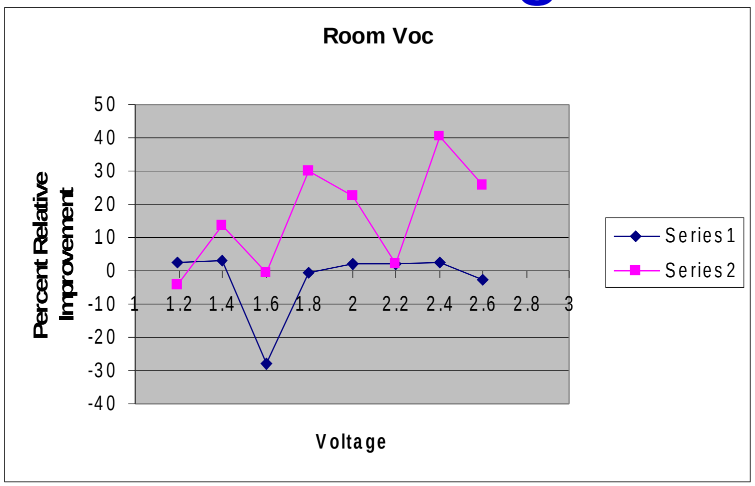
Light-Assisted Process

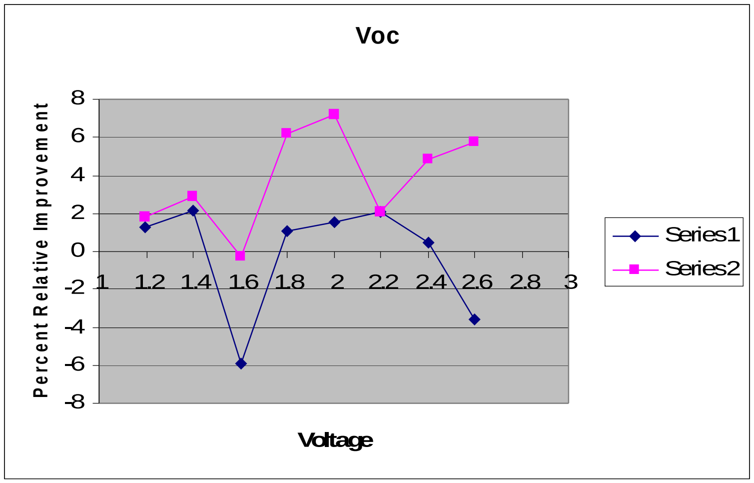
- Combined electrical bias and optical bias is used to achieve high selectivity in the transformation of ITO (or other electrode materials) into higher resistivity materials in shunted regions
- The solar cell being treated is immersed in electrolyte. A light bias and electrical bias are simultaneously applied to it for a few seconds.
- The light bias causes unshunted areas to produce a voltage, which reduces the leakage current due to electrical bias in these areas, which would otherwise lead to unwanted transformation of ITO in those areas. This minimizes loss of unshunted areas, which leads to greater solar cell efficiency

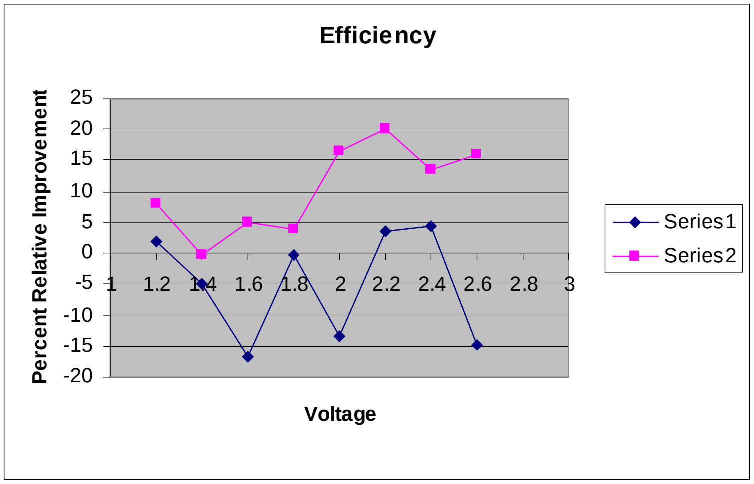
Apparatus

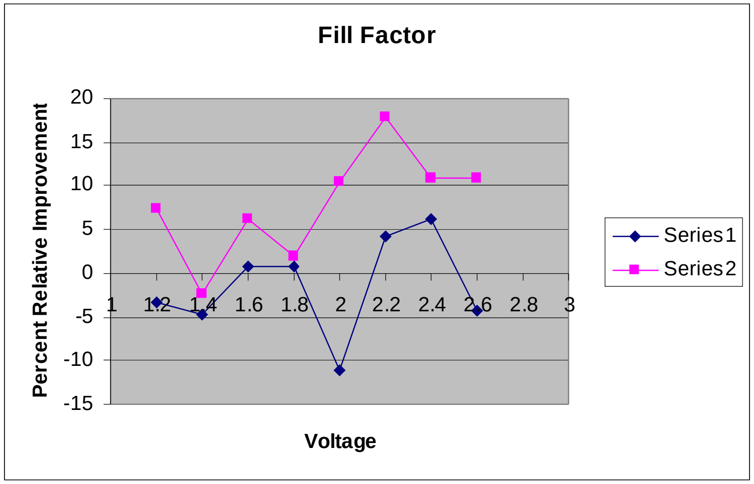

Bias Voltage
~1-30 seconds
Electrolyte,
e.g. $AlCl_3$
Light Source
Shunt
Electrode
Metal
a-Si
ITO (TCO)
Mesh Electrode

Earlier Comparison Between Light-assisted and Non-light-assisted Processes



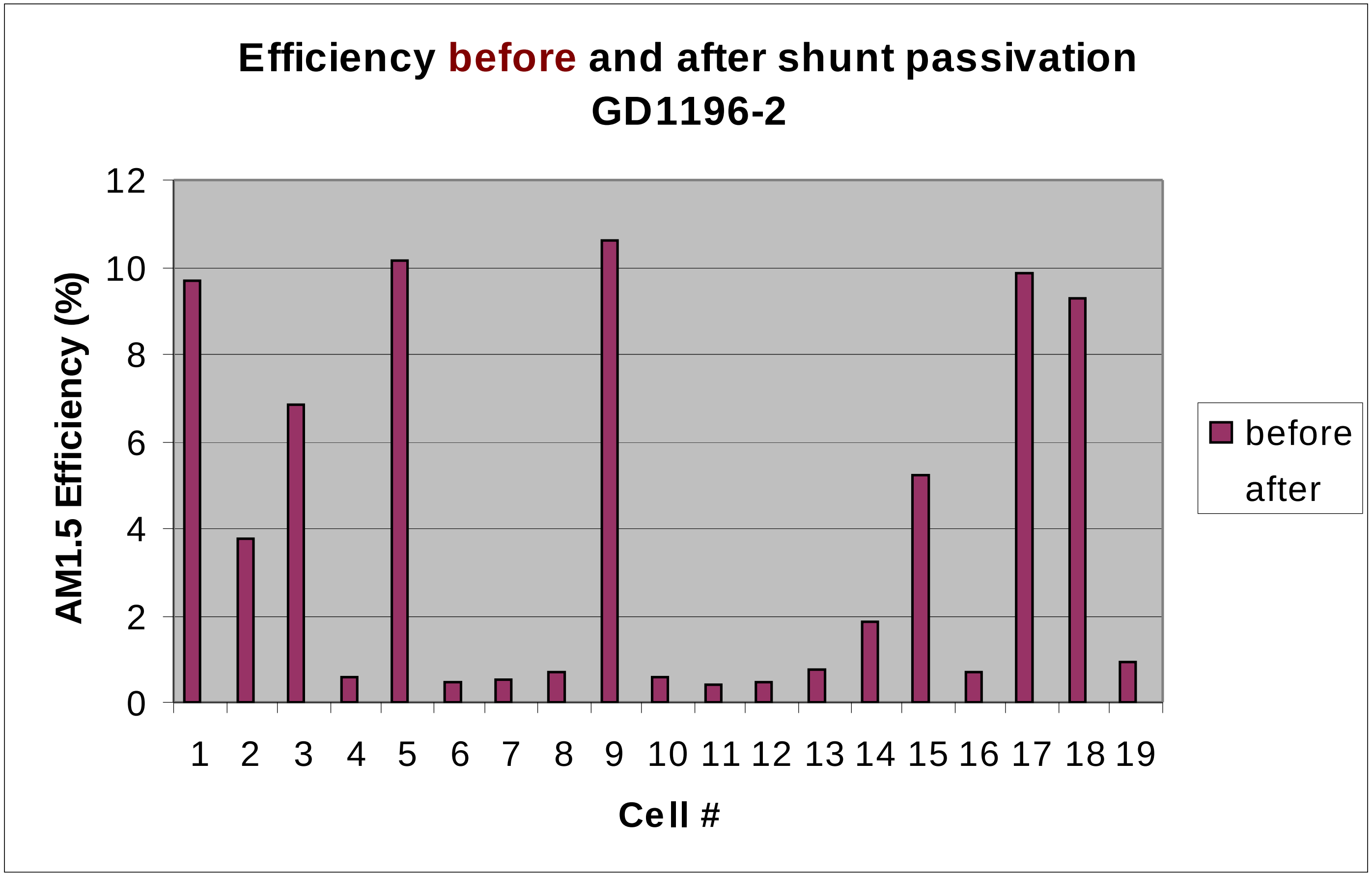






Series 1 = No light, **Series 2 = Light-assisted**

Effectiveness of Light-Assisted Shunt Passivation



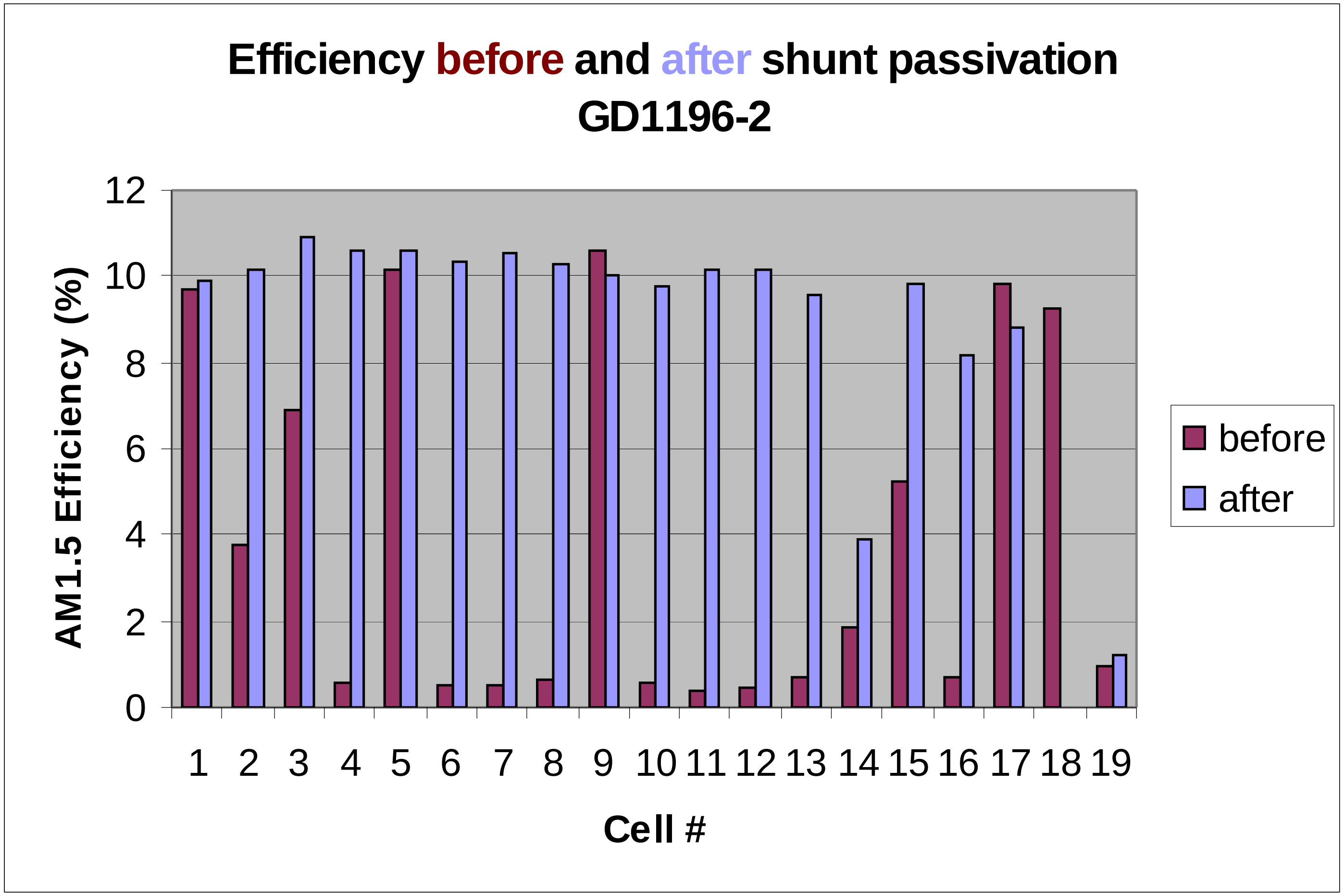
Bias = 2V

Light = 1 sun

Concn = 40 mS

Time = 10s

Effectiveness of Light-Assisted Shunt Passivation



Bias = 2V

Light = 1 sun

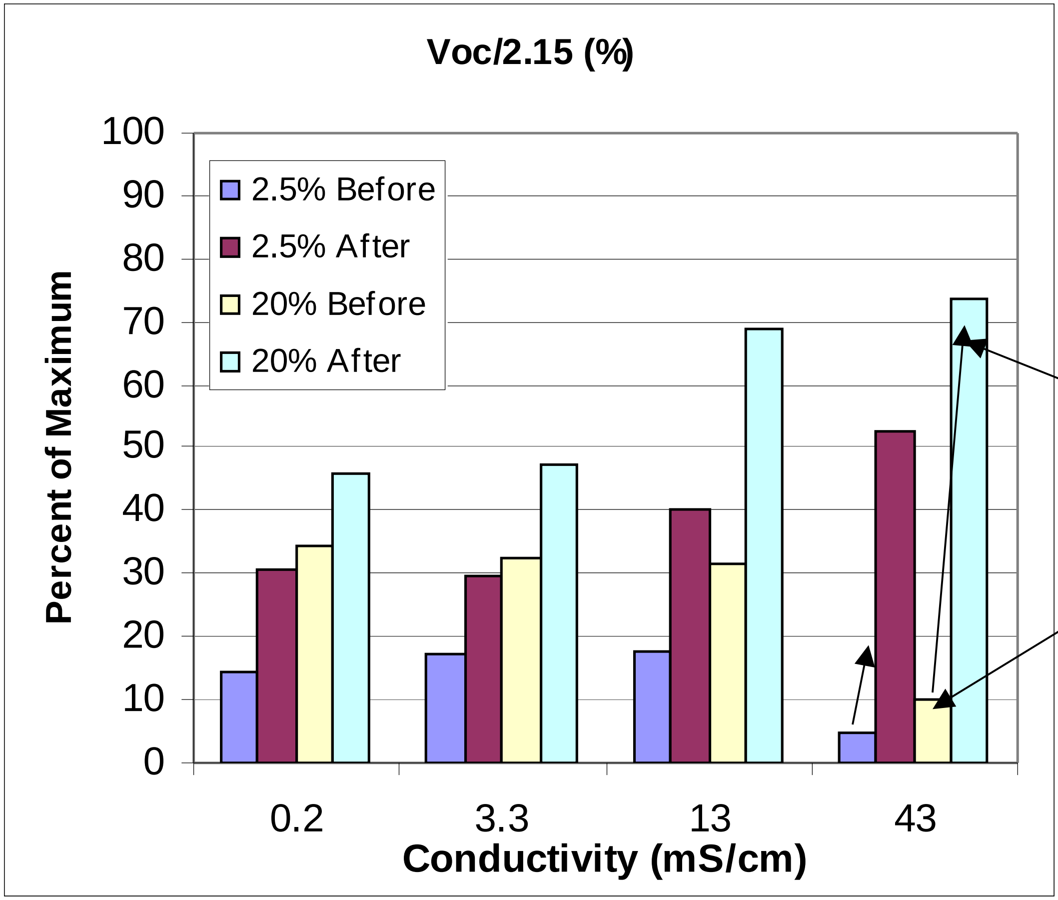
Concn = 40 mS

Time = 10s

Experiment – Best Conditions for Light Assisted Shunt Passivation

- Light assisted shunt passivation was carried out using different electrolyte concentrations (conductivity), passivation times, applied bias voltages and light intensities
- Shunting was induced with laser pulses
- A set of 18-20 triple-jn. a-Si cells was passivated at each condition
- Open circuit voltage under reduced light (2.5% of 1 sun and 20% of 1 sun), relative to the 1-sun unshunted Voc of 2.15V, was used as the metric of performance before and after shunt passivation
- Quantum efficiencies were also measured to compare light assisted and non-light assisted processes
- For better comparison, samples were chosen such that the sets had similar average open circuit voltages before shunt passivation
- Electrode spacing in all cases was 10 cm. A tungsten-halogen lamp was used for illumination and $AlCl_3$ was used as the

Electrolyte Concentration



Illumination = 1 sun

Passivation Time = 10s

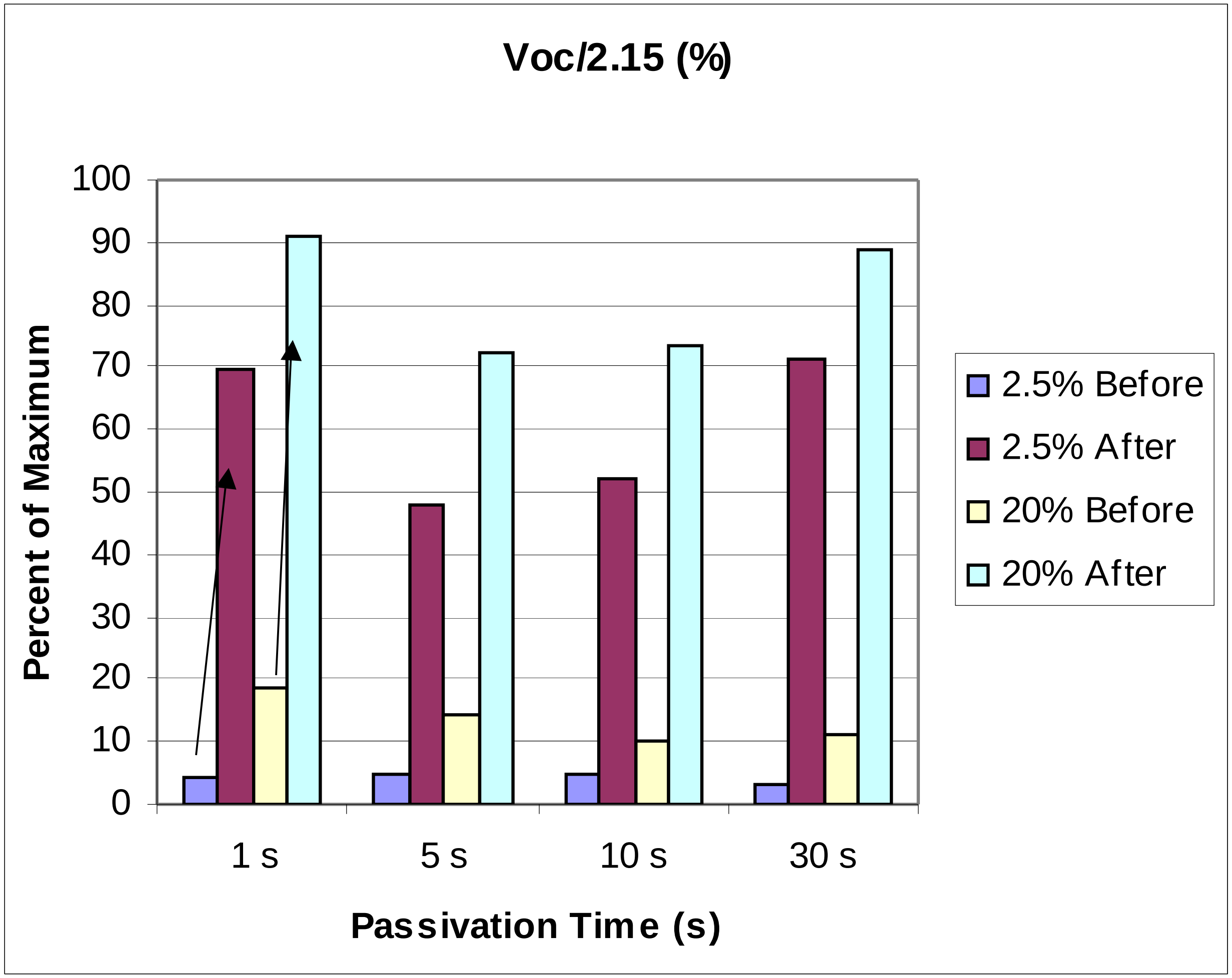
Bias Voltage = 2 V

Higher concentration gives more complete passivation, in general.

Voc measured with 20% light after passivation = 1.6V

Voc measured with 20% light before passivation = 0.2V

Passivation Time



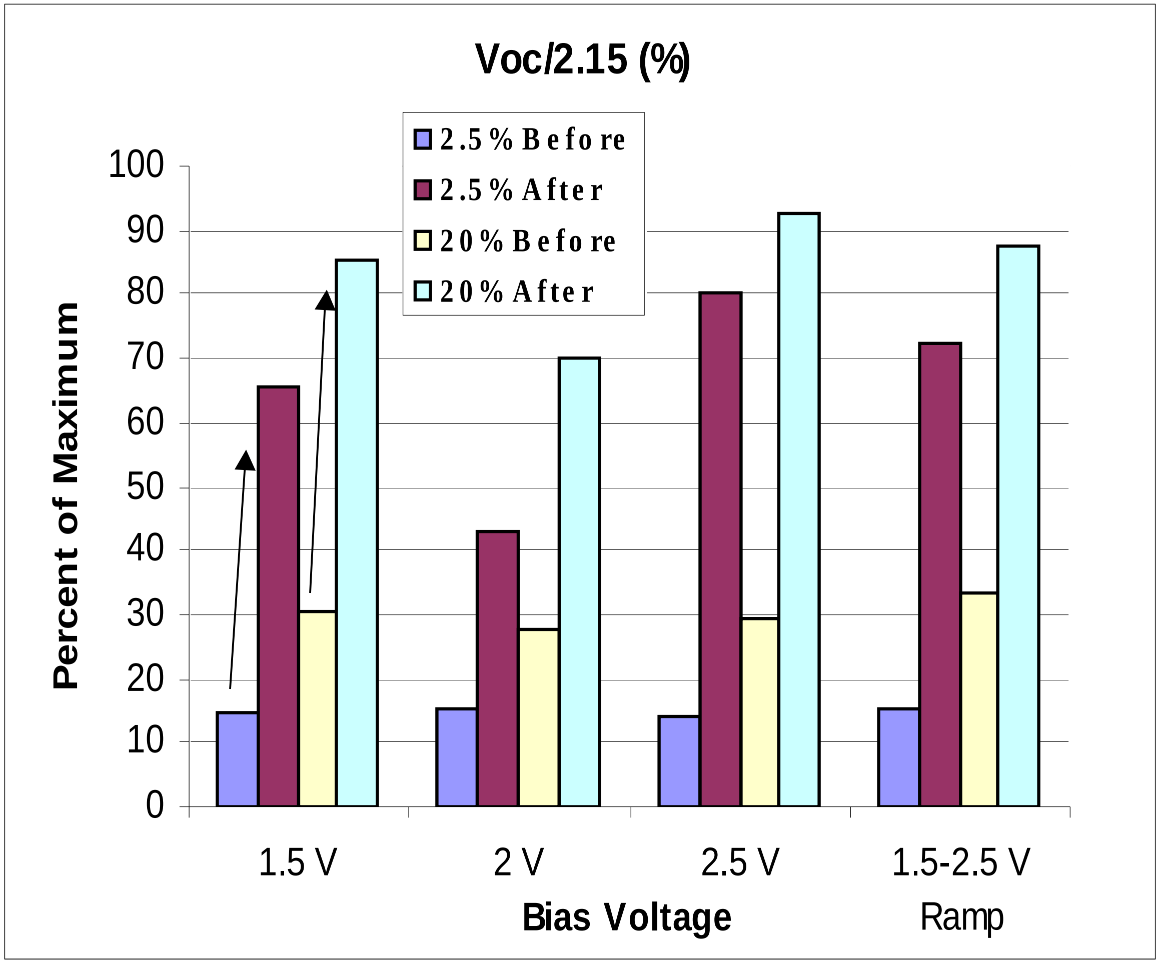
Illumination = 1 sun

Conductivity = 43 mS/cm

Bias Voltage = 2 V

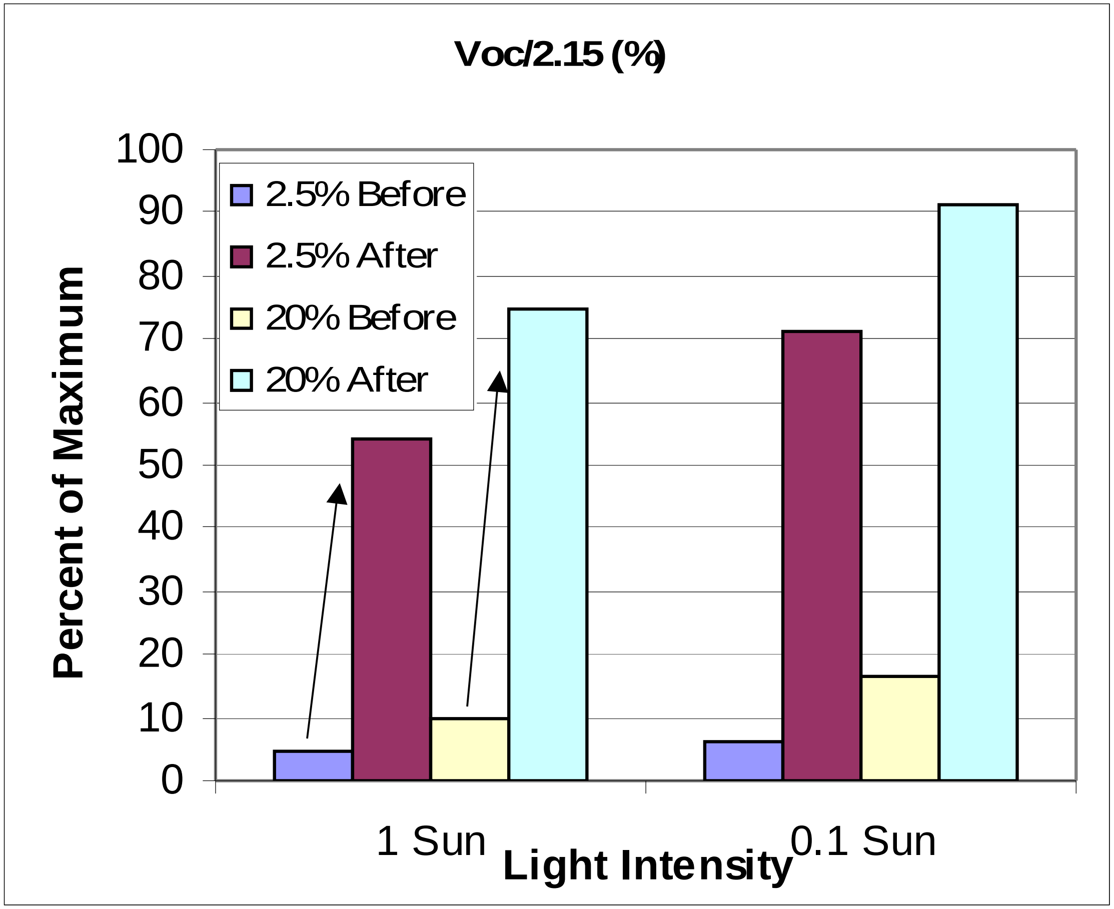
Wide range of passivation times from 1-30 s may be used

Bias Voltage



- Conductivity = 43 mS/cm
- Passivation Time = 10s
- Illumination = 1-sun
- In general, higher voltages produce more complete passivation, but light bias is needed to guard against unwanted conversion

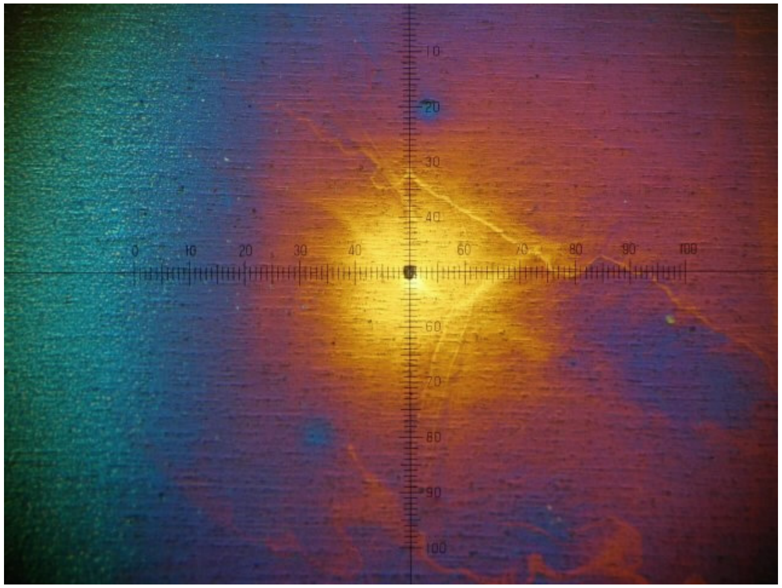
Light Intensity



- •Conductivity 43 mS/cm
- •Passivation Time 10s
- •Bias Voltage 2 V
- •There is a range of light intensity acceptable for light-assisted shunt passivation
- •However, at lower light intensity there is more unwanted conversion of ITO in unshunted region.

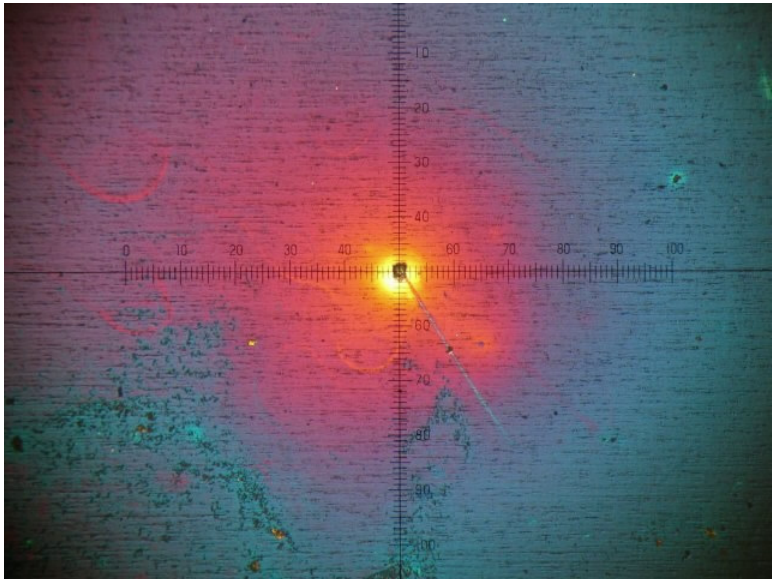
Area Affected by Shunt Passivation

- With light bias, the passivated area is small, resulting in less reduced current.
- Without light bias, one can still achieve small passivation area by using a lower bias voltage, but the passivation is not as complete in many cases.



No light, 2V bias

Area 1.4 mm^2

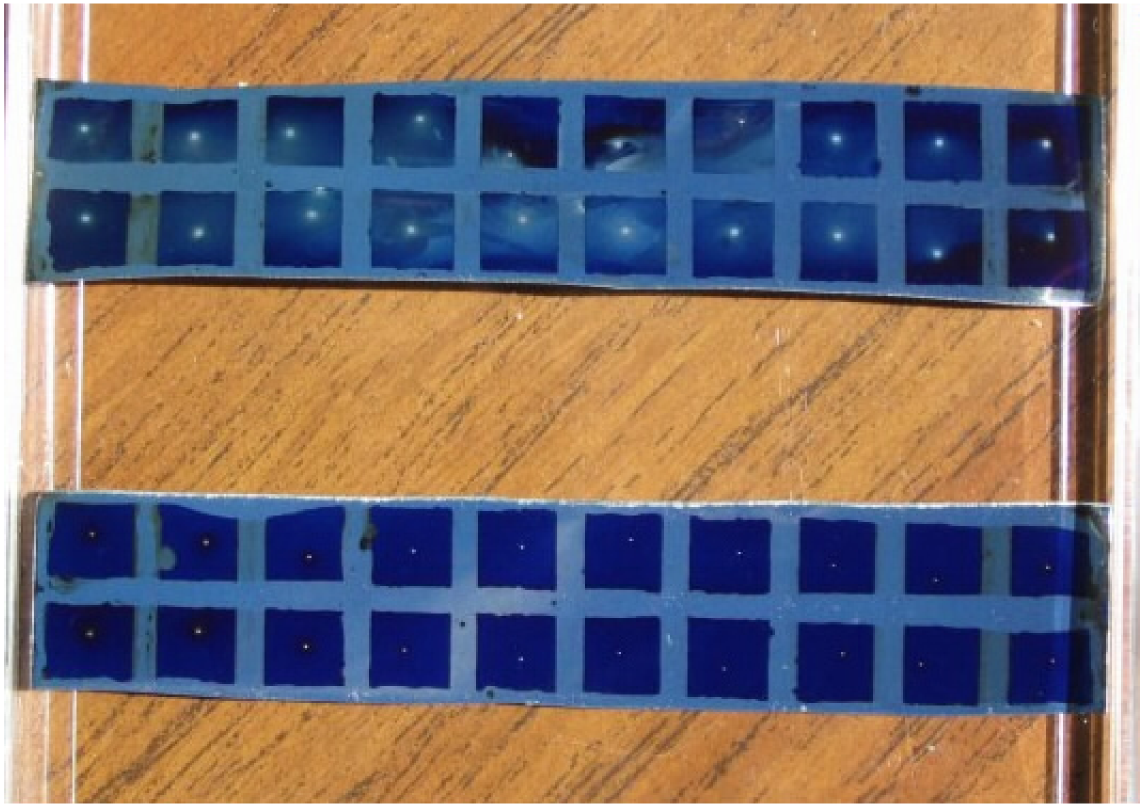


1 sun illumination, 3V bias

Area 0.16 mm^2

Passivation Time 10s, Conductivity 43 mS/cm. Samples had similar extents of shunting before passivation (as reflected by low light Voc).

Area Affected by Shunt Passivation

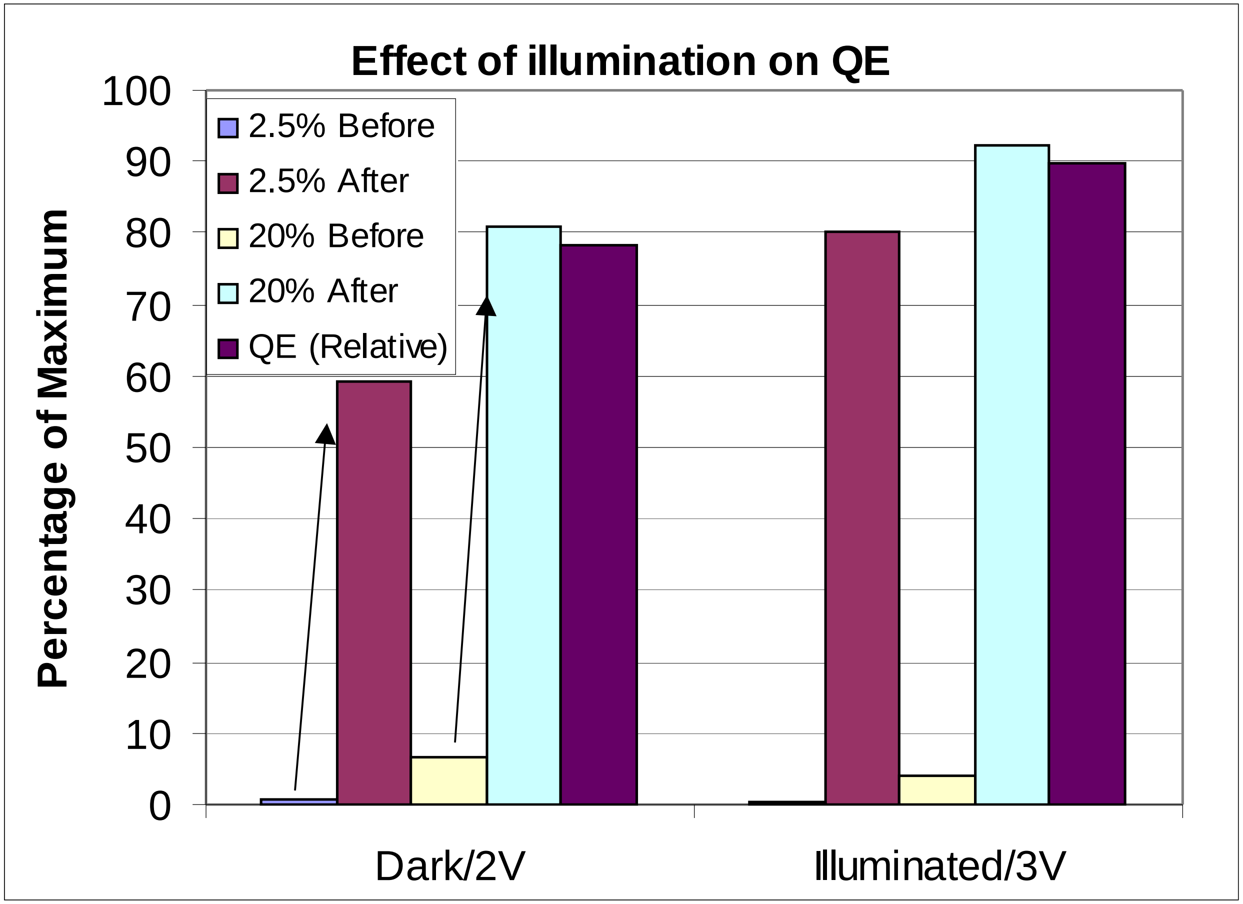


No Light,
2V

(passivation with 3V/no light leads to even larger passivation marks)

With Light,
3V

QE @400nm around affected areas, and open circuit voltages



- Avg. of 10 samples
- Illumination 1 sun
- Passivation Time 10s
- Conductivity 43 mS/cm
- Bias voltages chosen to operate the processes near their respective optimum points.

Summary

- Shunt passivation in the presence of light was indeed found to be better than in its absence.
- Time scales of 1-30s were found to be adequate for passivation.
- In general, higher solution concentrations lead to more complete passivation.
- There is a range of light intensity acceptable for light-assisted shunt passivation. However, at lower light intensity there is more unwanted conversion of ITO in unshunted region.
- In general, higher passivation voltages lead to more complete passivation of a variety of shunts, while light bias guards against unwanted conversion of the electrode.
- The process has been tested and found to perform well on triple, tandem and single a-Si and nc-Si cells with ITO top contact.
- Best conditions for triple cell: 2.5-3V for 10s with 1 sun illumination, 10 cm electrode spacing, 43 mS/cm $AlCl_3$ electrolyte, room temperature.